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(54) Gas Combustion With Low NO_x Emission

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ABSTRACT OF DISCLOSURE

The combustion of fuel gas to achieve improved thermal efficiency and to suppress NO_x formation is conducted by adding preheat to the combustion reactants followed by flameless combustion on the outer surface of a porous fiber burner. Preferably, all of the desired combustion air is preheated by indirect heat exchange with the flue gas resulting from the flameless combustion and the preheated air is then admixed with the fuel gas fed to the porous fiber burner. Waste heat from available independent sources may also be utilized to preheat the combustion reactants.

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This invention relates to gas combustion utilizing preheat for increased thermal efficiency and is particularly directed to such combustion resulting in low formation of nitrogen oxides (NO_x).

It is known that the use of preheat in gas combustion increases thermal efficiency, but unfortunately such combustion usually yields a greater content of NO_x in the combustion products or flue gas. Hence, with the growing concern and need to limit the discharge of NO_x into the atmosphere, the use of preheat in gas combustion is being restricted with resultant loss of thermal efficiency. Yet, rising fuel costs underscore the desirability of achieving greater thermal efficiency in gas combustion.

Accordingly, a principal object of this invention is to increase the thermal efficiency of gas combustion through the use of preheat while preventing a significant increase of NO_x formation through the use of a porous fiber burner.

Another important object is to recover heat from the hot flue gas as preheat of the air used in the combustion of fuel gas.

A further object is to provide simple and economic apparatus for conducting gas combustion with high thermal efficiency and low NO_x formation.

These and other objects and advantages of the invention will be evident from the description which follows.

In accordance with this invention, the combustion of fuel gas is conducted with the aid of preheat to achieve increased thermal efficiency and through the use of a porous fiber burner to prevent any significant increase of NO_x formation.

While preheat may be applied to the fuel gas or air or both, it is in most cases applied to the combustion air. Inasmuch as it takes, even stoichiometrically, at least about 10 volumes of air to burn one volume of methane, it is obvious that little can be gained in thermal efficiency by preheating the methane. Moreover, to attain more nearly complete combustion, an excess of combustion air is frequently used, generally about 10 to 15% more than the stoichiometric requirement. Hence, the benefit of preheating the fuel gas is further reduced.

While natural gas which is predominantly methane is abundantly and widely available as fuel gas, other hydrocarbon gases, usually propane, hydrogen alone or with carbon monoxide, and mixtures thereof may be used as fuel gas. Refinery gas and landfill gas are illustrative of gas mixtures that have fuel value and can be burned in accordance with this invention. When the fuel gas is predominantly hydrogen and/or carbon monoxide, preheating the fuel gas as well as the combustion air may be advisable because it takes only about 2.5 volumes of air to burn a volume of hydrogen and/or carbon monoxide.

Essential to the prevention of a substantial increase in the formation of NO_x when the combustion reactants, i.e., the combustion air and/or fuel gas, have been preheated

is the use of a porous fiber burner. Such burner produces flameless combustion; the combustion reaction occurs on the outer surface of the porous fiber layer of the burner causing the outer surface to incandesce and thereby yield a high proportion of radiant heat. A preferred flameless, radiant burner used in accordance with this invention is disclosed in Canadian Pat. No. 759,755 and more particularly is disclosed in Canadian Pat. No. 822,665. A porous fiber burner containing powdered aluminum as taught in Canadian Pat. No. 822,665 suppresses the formation of carbon monoxide and, therefore, is highly favored for the purposes of this invention. Unlike ordinary flame-type burners which often are supplied with primary and secondary air to carry out the combustion of fuel gas, the total air desired for combustion is passed through the porous fiber burner admixed with the fuel gas.

In general, the greater the amount of preheat transferred to the combustion reactants, the greater is the increase in thermal efficiency which, for the purposes of this invention, is defined as the percentage (%) of the thermal input into the furnace or combustion zone which is converted into useful heat. Thus, if a furnace has a thermal efficiency of 80%, it follows that 20% of the thermal input is lost, principally as heat in the flue gas vented outdoors. Another source of loss in thermal efficiency is incomplete combustion of the fuel gas as evidenced by carbon monoxide, hydrocarbons, hydrogen and even soot (carbon) in the flue gas.

For simplicity and ease of determination, the amount of preheat given to the combustion reactants is herein expressed

as the temperature of the preheated reactants in degrees Fahrenheit (°F). While residential furnaces will usually have the combustion reactants preheated by passing the required air in indirect heat exchange with the hot flue gas before it is vented, commercial and industrial furnaces will have, in many cases, available preheat for the combustion reactants from the waste heat of operations that may or may not be associated with the furnaces. Such waste heat may be utilized to augment preheat derived from the flue gas of the furnace or to provide all of the desired preheat.

In most cases, the amount of preheat that can be practically imparted to the combustion reactants will raise the temperature of the total combustion air to a value in the range of about 200 to 1000°F. A preheat temperature below 200°F does not increase the thermal efficiency of a furnace enough to justify the cost of a heat exchanger. A preheat temperature above 1000°F is rarely attainable economically and with some fuel gases may cause preignition or flash-back before the combustion reactants pass through the porous fiber burner.

As reported in a paper presented by R. C. Bojka et al at the American Flame Research Committee's International Symposium on Industrial Fuel Technology held in Chicago on October 5-7, 1981, a conventional flame-type burner yielded a rapidly increasing amount of NO_x in the flue gas as the preheat temperature was increased. Thus, at a preheat temperature of 660°F the NO_x content of the flue gas was about 220 parts per million (ppm) of flue gas on a dry basis and

corrected to 0% oxygen and at a preheat temperature of 900°F the NO_x content rose to about 370 ppm. In sharp contrast to these very high NO_x contents, a porous fiber burner made in accordance with the teachings of Canadian Pat. No. 822,665 produced a flue gas with a NO_x content of 16-17 ppm without any preheat, and preheating the combustion air to several temperatures as high as 664°F did not increase the NO_x content beyond 18.7 ppm. Obviously, the use of preheat with a flame-type burner is environmentally intolerable but with a porous fiber burner is not only acceptable but also desirable because the resulting increase in thermal efficiency complies with the national program to conserve fuel.

The further description of the invention will refer to the appended drawings of which:

FIG. 1 is a diagrammatic representation of a combustion system embodying a preferred form of the invention; and

FIG. 2 is a graph of the increased thermal efficiency of a furnace utilizing preheat in accordance with this invention versus the thermal efficiency of that furnace without preheat.

FIG. 1 shows furnace 10 equipped with porous fiber burner 11 in the bottom portion thereof. The combustion reactants flow to burner 11 through pipe 12 which is supplied with fuel gas by pipe 13 and with preheated air by pipe 14. Flameless combustion takes place on the exterior surface of burner 11, yielding radiant heat and hot flue gas. Water or other desired fluid enters heat exchanger coil 15 within furnace 10 at inlet 16 and flows down through coil 15 to

abstract heat from the rising hot flue gas and to absorb infra-red radiation from burner 11. The thus heated fluid leaves coil 15 at outlet 17 for its intended utilization. The cooled but still hot flue gas discharges from furnace 10 through pipe 18 into heat exchanger 19. All of the combustion air supplied to burner 11 enters coil 20 in exchanger 19 through inlet 21 and flows countercurrent to the flue gas which leaves exchanger 19 through pipe 22. The thus preheated combustion air passes from coil 20 through pipe 14 to pipe 12 which feeds burner 11.

To illustrate the benefit resulting from preheating the combustion air, a residential furnace operating with natural gas having a heating value of 1000 BTU (British Thermal Unit) per standard cubic foot and with 15% excess air at an ambient temperature of 70°F has a thermal efficiency of 84% and discharges the flue gas at a temperature of 750°F. When the flue gas is used to preheat the same quantity of combustion air to a temperature of 400°F as shown in FIG. 1, the thermal efficiency of the furnace is increased to 91%. At the same time, the NO_x content of the flue gas is substantially unchanged by the preheat; in both cases the NO_x content is below 18 ppm. It is well to note that the flue gas from the porous fiber burner yields in both cases a flue gas free of carbon monoxide and containing not more than 5 ppm of unburned hydrocarbons.

FIG. 2 is a graph showing how the thermal efficiency of a furnace operating with natural gas and 15% excess air at an ambient temperature of 70°F (labeled Ambient % T.E.

along the abscissa) is increased by preheating the combustion air to four different temperatures. The graph lines marked 200, 500, 750 and 1000 represent the preheat temperature in $^{\circ}F$ of the combustion air flowing to the porous fiber burner and the resulting increased thermal efficiency is read along the graph ordinate labeled Preheat % T.E. For example, a furnace having an Ambient 70% T.E. will yield a Preheat 76% T.E. when the combustion air is preheated to 500°F. Another furnace with an Ambient 55% T.E. will give a Preheat 64% T.E. when the 15% excess air is preheated to a temperature of 750°F. With still another furnace, an Ambient 80% T.E. is raised to a Preheat 94% T.E. by preheating the combustion air to a temperature of 750°F.

Tests conducted pursuant to this invention revealed some additional valuable features. Thus, a burner formed according to the teachings of Canadian Pat. No. 822,665 by depositing a porous fiber layer on a stainless steel screen and designed for a heat input capacity of 30,000 BTU per hour when fed with natural gas having a heating value of 1000 BTU per standard cubic foot was used in several combustion tests with the burner in the open air (not within a furnace). All of the tests were conducted with 10% excess air. With preheat temperatures reaching 800°F for the admixed air and natural gas, the temperature of the radiant surface of the burner did not vary more than about 30°F from the average temperature of 1730°F when the burner was supplied with natural gas at the rate of 30,000 BTU per hour. When the flow of natural gas was reduced to 20,000 BTU per hour, the tem-

perature of the radiant surface of the burner decreased to 1650°F while operating with a preheat temperature of 930°F. Hence, the porous fiber burner can operate successfully when the heat input is materially reduced below its design capacity and with preheat temperatures extending to about 1000°F and yet with these variations in operating conditions the NO_x content of the flue gas remains surprisingly low, generally below about 20 ppm.

When the fuel gas is substantially pure hydrogen, it has been found that there is a tendency for the combustion of the hydrogen-air mixture on the exterior surface of the porous fiber burner to move inward through the porous fiber layer and cause flashback of the combustion reactants. However, as disclosed by Niels E. Scholar in a report entitled: EPA Van Operational Manual, No. EPA-600/9-76-020, August 1976, flashback in a porous fiber burner is prevented by placing close to the inner surface, usually a metal screen, of the porous fiber burner, a perforated ceramic plate with a gold film deposited on the side of the ceramic plate facing the inner surface of the burner. Such known means of preventing flashback should obviously be used whenever a fuel gas exhibits a flashback tendency in carrying out the combustion process of this invention.

The foregoing disclosure has pointed out the great flexibility in operating conditions and amount of preheat given the combustion reactants made possible by the use of a porous fiber burner which in all cases yields a flue gas with a very low NO_x content and substantially free of carbon

monoxide. Those skilled in the art will visualize many modifications and variations of the invention without departing from its spirit or scope. For instance, while all of the combustion air is passed through coil 20 in heat exchanger 19 of FIG. 1 only part of the air may be so preheated and combined with the remainder of the air at ambient temperature or preheated with waste heat from an independent source. Similarly, separate heat exchanger 19 may be eliminated by providing an air heating coil like coil 20 within furnace 10 near outlet pipe 18 for the flue gas. Accordingly, only such limitations should be imposed on the invention as are set forth in the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. The combustion of fuel gas to achieve improved thermal efficiency and low NO_x formation, which comprises forming a preheated mixture of said fuel gas and all of the desired combustion air, passing said preheated mixture through the porous fiber layer of a porous fiber burner, and burning said fuel gas on the exterior surface of said fiber layer so that said exterior surface incandesces substantially without flame and hot flue gas is produced without significant increase of NO_x formation over the NO_x formation in the absence of preheat.

2. The combustion of fuel gas according to claim 1, wherein hot flue gas is used to provide preheat to the mixture of said fuel gas and combustion air.

3. The combustion of fuel gas according to claim 1, wherein the desired combustion air is heated to a temperature of at least 200°F by indirect heat exchange with hot flue gas, and the thus heated air is mixed with said fuel gas to form the preheated mixture which is passed through the porous fiber layer.

4. The combustion of fuel gas according to claim 1, 2 or 3, wherein said fuel gas is natural gas and the desired combustion air is not more than 15% in excess of the stoichiometric requirement.

5. The combustion of fuel gas according to claim 1, 2 or 3, wherein all of the combustion air is heated to a temperature of at least about 400°F by indirect heat exchange with hot flue gas, and the porous fiber layer contains a uniformly distributed, small amount of fine aluminum powder.

6. In the combustion of fuel gas, the improvement of increasing the thermal efficiency of said combustion and simultaneously preventing the formation of NO_x in excess of about 20 ppm in the resulting flue gas, which comprises heating the desired combustion air to a temperature of at least 200°F, passing the heated air together with said fuel gas through the porous fiber layer of a porous fiber burner, and effecting flameless combustion of said fuel gas on the outer surface of said porous fiber layer with the result that said outer surface radiates infra-red and the formation of NO_x in excess of about 20 ppm in said flue gas is prevented.

7. The improvement of claim 6, wherein the desired combustion air is not more than 15% in excess of the stoichiometric requirement and all of said air is heated by indirect heat exchange with the flue gas.

8. The improvement of claim 6, wherein the fuel gas is natural gas, and all of the air heated to a temperature of at least about 400°F.

9. The improvement of claim 6, 7 or 8, wherein the porous fiber layer contains a uniformly distributed, small amount of fine aluminum powder.

10. An improved combustion system for fuel gas to produce flue gas with low NO_x content and to yield increased thermal efficiency, which comprises a furnace equipped with a porous fiber burner, a heat exchanger connected to said furnace to receive the flow of flue gas from said furnace, a passage in said heat exchanger for the flow of combustion air therethrough, a pipe connected to said passage and to the inlet of said burner to permit the flow of heated air from said passage into said burner, and means for feeding said fuel gas into said burner.

11. The improved combustion system of claim 10, wherein the porous fiber layer of the burner contains a uniformly distributed, small amount of fine aluminum powder.

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FIG. 1

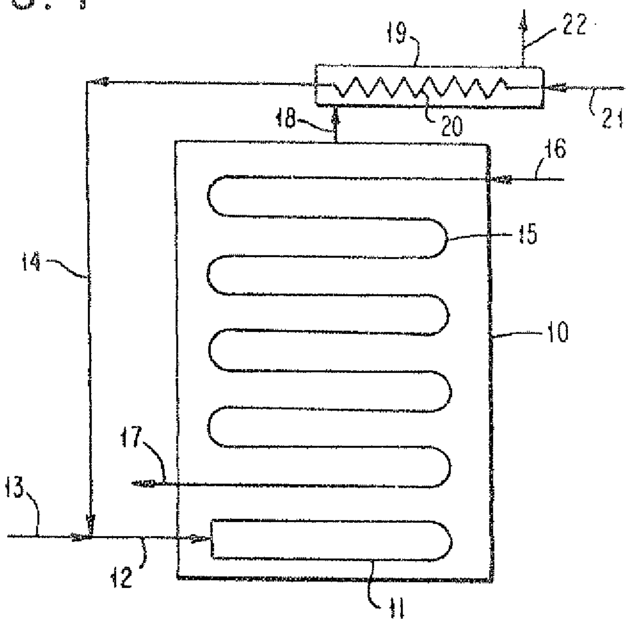
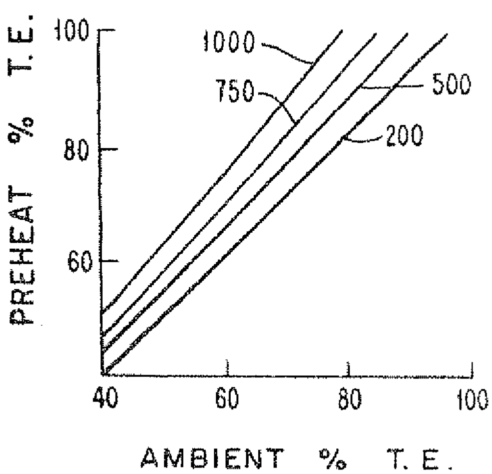


FIG. 2



Gowling & Henderson